Impact of Climate Change on Agricultural Cropping Patterns in the MENA Region

(ICCAC)

November 2013

CEDARE

الجمعية العلمية الملكية
Royal Scientific Society

Water and Environment Centre

fhi360
THE SCIENCE OF IMPROVING LIVES

CONTENTS

ABSTRACT

Global climate change may have dramatic impacts on agriculture and food security. This is especially so in the Middle East/North Africa (MENA) because of rainfall and groundwater scarcity. In Report Title (citation), Schönhart et al. state that "crop rotations are an important factor for the design and implementation of sustainable agricultural systems. Integrated agricultural land use models increasingly acknowledge the role of crop rotations by assessing economic and environmental impacts of agricultural production systems. However, insufficient data on crop rotations often challenge their implementation."

This report summarizes the background literature of cropping patterns and examines the agricultural practices of the three MENA countries Egypt, Jordan, and Yemen, and looks closely at strategic crops and model input data in these nations. This report is a result of a desk-review; its intention is to study the impact of various climate change scenarios on crop yield and water requirements for the selected crops in each country. The CROPWAT model developed by the Land and Water Development Division of the Food and Agriculture Organization FAO was used for this research as a decision-support system.

INTRODUCTION

Climate change is quickly becoming one of the most pressing global challenges and a threat to many critical sectors of civilization. Agriculture is one of the most climate-sensitive sectors, as it is continuously and directly affected by temperature and precipitation. The impact of climate change on agriculture could result in problems with food security, and may also threaten livelihoods and economic stability. Agricultural practices in Egypt, Jordan, and Yemen are highly researchable, with the objective of improving agricultural water management and cropping patterns as the effects of climate change become apparent.

EGYPT

Egypt is located in the north-eastern corner of Africa and has an area of 1,001,450 km^2. It extends 1,105 km from north to south and up to 1,129 km from east to west. The main physical districts in Egypt are the Nile Valley and Delta, the Western Desert, the Eastern Desert and the Sinai Peninsula. F Egypt, and particularly the Nile, is regarded as one of the world's oldest agrarian civilizations. The current population has reached 83.7 million with an annual growth rate of 1.9% (CIA 2013).

Precipitation is very limited in Egypt with the most significant rainfall concentrated in a small strip along the northern Mediterranean coastline; historically and today, the country depends entirely on the Nile for its water. The High Dam in Aswan was built to improve accessibility of water and create a solid and steady supply. According to negotiated agreements with Nile Basin states, Egypt's portion from the Nile is approximately 55.5 billion m^3 per year from the total flow. The nation's absolute accessible water assets are assessed at about 73.8 billion m^3 per year. The aggregate water utilization is approximately 62.6 billion m^3. Of this, agricultural activities constitute up to 85% of total demand (El-Nahrawy 2011).

The Egyptian economy depends intensely on the agricultural sector for food, clothing, and national income. It is one of the most labor-intensive industries, directly and indirectly providing jobs for 55% of Egyptians and utilizing 30% of the official labor force (SADS 2009). Agriculture contributes about 17% of national GDP and 20% of all outside trade profit (SADS 2009). The recorded impart from creature protein in 1997 was in the vicinity of 21 g/day per capita; this will need to increase to 24 g/day per capita by 2017. The proposed protein consumption by the FAO is approximately 30 g/day/person (SADS 2009).

Over 90% of Egypt is desert with cultivable land in the vicinity of 3.5 million ha (8.4 million *feddan*). This represents about 3.5% of the country's total land (SADS, 2009). About 3,276,000 ha (7.8 million *feddan*) lie inside the Nile Basin and Delta, while 210,000 ha (500,000 *feddan*) are fed by desert springs (oases). Of the total cultivable land in the Nile Basin and Delta region, approximately 2,268,000 ha (5.4 million *feddan*) are considered old lands (i.e., historically irrigated by the Nile) and 1,008,000 ha (2.4 million *feddan*) are new reclaimed lands (El-Nahrawy 2011).

CROPS

In Egypt, a majority of farmland is cultivated annually with only 6% of total crops planted permanently. As shown in Table 1, the total cropping area has grown by nearly two million ha over the last four decades, increasing from 4.5 million ha in 1980/4 to 6.9 million ha in 2008/9. This period also saw significant changes in general cropping patterns. As summarized in Egypt's FAO country profile, "cereals, fruit, sugar crops and vegetables areas have increased from 2.0, 0.17, 0.11 and 0.43 M ha in 1980/84 to 2.98, 1.43, 0.25 and 0.74 M ha respectively in 2008/09. While fiber crops, oil crops, fodder crops and food legume areas have decreased from 0.48, 0.08, 1.28 and 0.14 M ha in 1980/84 to 0.22, 0.02, 1.17 and 0.13 M ha respectively in 2008/09." (FAO 2011).

Almost all of the nation's cropland is irrigated. Irrigated areas in Egypt total about 3,422,178 ha, of which 88.5% use surface irrigation (FAO 2011). Drip irrigation accounts for seven percent, and five per cent is sprinkler irrigation. The main source of irrigation water is surface water (85%), 11% comes from groundwater, and the remaining six per cent is a mix of surface water and groundwater. (FAO 2011).

Table.1: Changes in Area Harvested by Crop Group (in M ha) from 1980 to 2009 in Egypt

	Year 1980/84		Year 1990/91		Year 2000/01		Year 2006/07		Year 2007/08		Year 2008/09	
Crop Group	area	%	area	%	area	%	area	%	area	%	area	%
Cereals	2	42.6	2.25	46.2	2.65	46.1	2.96	43.7	2.97	42.4	2.98	42.9
Legumes	0.14	2.9	0.15	3.2	0.17	3	0.12	1.8	0.11	1.6	0.13	1.9

Fibers	0.48	10.2	0.4	8.3	0.31	5.4	0.27	4	0.25	3.6	0.22	3.2
Sugar crops	0.11	2.4	0.13	2.6	0.19	3.3	0.21	3.1	0.23	3.3	0.25	3.6
Oil crops	0.08	1.8	0.03	1.9	0.12	2.1	0.03	0.4	0.02	0.3	0.02	0.3
Fodder crops	1.28	27.3	1.13	23.1	1.18	20.7	1.18	17.4	1.15	16.4	1.17	16.9
Fruit	0.17	3.6	0.23	4.8	0.48	8.4	1.37	20.2	1.4	20	1.43	20.6
Vegetables	0.43	9.2	0.48	9.9	0.7	11	0.63	9.4	0.87	12.4	0.74	10.6
Total	4.58	100	4.81	100	5.75	100	6.77	100	6.37	100	6.94	100

Source: Economic Affairs Department, Agricultural Statistics Bulletin (2009), Ministry of Agriculture, Cairo, Egypt.

SOIL

As is the case with water, in terms of soil and topography, the Nile Valley and Delta are the two most relevant areas for the agriculture sector. Although they constitute just 5.5% (35,000 km^2) of the country's land area, the Nile Valley and Delta regions support 99% of the population through agriculture and food production (FAO 2011).

Most of the soils in the Nile Valley and Delta, are alluvial. They formed through the annual deposits of suspended solid matter when the Nile would flood (Hamdi 2001). This matter is made up of eruptive and metamorphic rocks that come from the Ethiopian plateau, and which have been broken down and weathered through physical, chemical, and biological processes.

Figure 1 shows the different soil types of the Nile Delta and Nile Valley. Table 2 shows the major soil groups and land cover in Egypt.

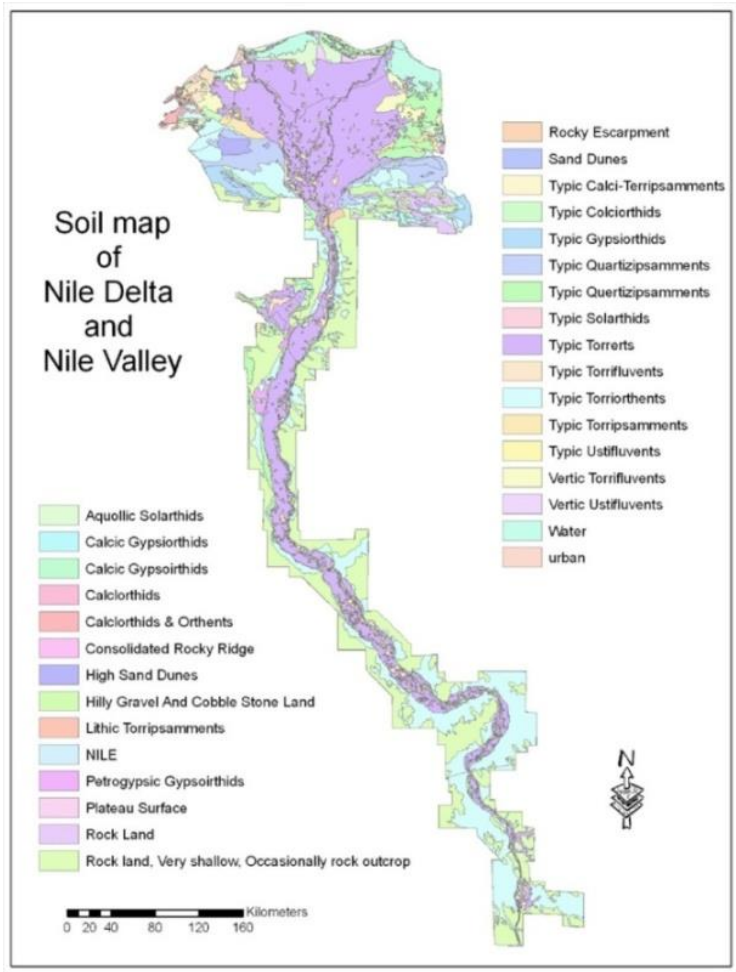


Figure 1: Soil Classification of the Nile Delta and Nile Valley (Source: FAO 2011)

Table 2: Major Soil Groups and Land Cover in Egypt

Soil groups/land cover	Percentage of total
Arenosols (AR)	25.80
Calcisols (CL), associated with Gypsisols (GY)	0.37
Calcisols (CL)	9.12
Fluvisols (FL)	0.80

Soil groups/land cover	Percentage of total
Leptosols (LP)	24.87
Water Bodies	15.44
Regosols (RG)	8.68
Solonchaks (SC)	0.48
Vertisols (VR)	4.85
Soils outside the area surveyed	9.59

Source: El Nahrawy, FAO 2011

CLIMATE CHANGE

Changes in precipitation in Egypt due to climate change will not be of major significance, as the country depends primarily on irrigated agriculture. Much more important will be precipitation changes at the main headwaters of the Nile in Ethiopia, which will affect the supply of Egypt's water resources and its overall vulnerability.

El-Raey et al. (1995) identified water resources as one of the three most vulnerable sectors to climate change in Egypt, the others being coastal zones and agricultural resources. Climate change will affect not only Egypt but the whole Nile River basin, which includes 10 other countries.

The estimated changes in potential evapotranspiration (PET), which is correlated with temperature, and precipitation changes according to three selected Global Climate Models (GCMs), have wide range as shown in Table 1. These were taken from the change between each model's estimate of the base period (1910–1990) and each model's simulation of the end of the 21st century (2081– 2098) (UNDP 2013).

Table 3: Estimated Change in Temperature and Precipitation for Cairo 2030-2060

	2030			**2060**		
	CGCM63	**ECHAM**	**MIROC-M**	**CGCM63**	**ECHAM**	**MIROC-M**
Annual temperature °C	0.9	0.9	1.0	2.0	1.9	2.2
Annual precipitation %	-4	0	-5	-10	0	-10

JORDAN

Jordan occupies an area of approximately 90,000 km^2. The country's population was estimated at 6.440 million in 2012, of which 82.6% are concentrated in large cities (urbanized) while 17.4% live in remote-rural areas (Department of Statistics, annual report 2012). Jordan is one of the most water-scarce countries in the world and only about 5% of its land is considered arable. It is a great challenge to promote food security while conserving resources.

Approximately 20% of the Jordanian population depends on the agricultural sector, which formally employs seven per cent of the workforce. According to the IFAD report "Jordan: Agricultural Resources Management Project," "the contribution of agriculture to Jordan's GDP, including forestry and fisheries, declined from 6% in 1995 to 4.5% in 1999 due to drought during the period 1997-1999" (IFAD 2012). Although the agricultural sector itself is not considered very large, it still indirectly contributes to about 28% of the nation's GDP through linkages with other industries and economic activities (IFAD 2012).

Agriculture consumes approximately 75% of available water resources in Jordan. While this is mostly through rain-fed agriculture, about 76,000 ha of the Jordan Valley and Badia regions are irrigated (Shantanawi 2002). In addition to groundwater sources, recycled wastewater and desalination are increasingly being considered to augment agricultural water supplies.

Jordan’s agricultural sector can be divided into four types: fruit trees, field crops, vegetables, and livestock. Main vegetable crops include tomatoes, potatoes, cucumber, melon, cauliflower and cabbage, and eggplant and zucchini (Agriculture and Agri-Food Canada 2010). These occupy approximately 48562 hectares acres of farmland. Fruits, including olive, almond, peach, apricot, plum, apple, pear, pistachio and citrus trees, as well as grape vines, are grown on about 380,000 acres of land. Field crops including legumes, cereals, wheat, lentils, chickpeas, corn, and sesame are grown on about 28328 hectares of land (Agriculture and Agri-Food Canada 2010). A summary of the harvested areas and average yields of major field crops in Jordan is presented in Table 4.

Table 4: Planted Area, Harvested Area, Average Yield and Production of Field Crops in 2011

(Jordan)

Crops	Harvested Area	Average Yield	Production
Wheat	143,296.5	0.14	19,801.2
Barley	277,933.5	0.11	29,285.4
Lentils	967.0	0.08	82.0
Vetch	14,127.5	0.06	817.0
Chickpeas	8,735.3	0.25	2,157.0
Maize	7,955.4	2.07	16,460.1
Sorghum	6,933.0	2.52	17,496.4
Broom millet	2.3	1.22	2.8
Tobacco, local	90.1	0.59	52.8
Garlic	153.2	1.51	231.8
Vetch, common	748.7	1.57	1,174.8
Sesame	374.5	0.17	62.9
Clover, trifoliate	21,953.0	4.55	99,973.1
Alfalfa	100.0	3.50	350.0

Others	445.0	0.05	24.1

Source: Department of Statistics 2012**.**

SOIL

There are at least three distinct biogeographical regions in Jordan (Damhoureyeh 2010; Al Qudah 2001).

- The Mediterranean region occupies the northern highlands from Irbid to Ras-Naqb. The most common soil type is Terra Rosa and the yellow soil Rendzina. This is considered the most fertile region of the country.
- The Irano-Turanian region surrounds the Mediterranean regions, separating it from all other regions. Its soils are typically calcareous (transported by wind).
- The Badia is a desert region and the largest in Jordan. It is largely infertile and contains mostly aridisols and entisols. These are either Hammada, clay, saline, sandy or calcareous.
- The sub-tropical or Sudanian region starts at Al-Karamah in the north and continues to the Gulf of Aqaba. The soil here is typically alluvial and is either saline, sandy or granite.

CLIMATE CHANGE

A detailed analysis of mean monthly air temperature and mean annual rainfall was the main focus of the Kingdom’s Second National Communication (SNC) report. The selected time series for the analysis was a period of 45 years (1961–2005). The data complied with the requirements of the World Metrological Organization (WMO) and the latest “normal period‟ defined by the organization (1970 to 2000) was included. An 8–20% decrease in rainfall was predicted, along with a temperature increase in the range of 0.5–2.0 °C.

According to the SNC report, the most probable national climate change scenario would be an increased air temperature of 1° C and 2° C by 2030 and 2050, respectively. All surface water basins would suffer from decreased rainfall in the range of 10–20%, except those of the eastern desert and the Northern *wadis* of the Jordan River. It is worth mentioning that precipitation in the latter basin is normally low, and therefore the expected increase in rainfall in these basins will not significantly affect the overall negative impacts of climate change (Al-Bakri et al. 2013).

YEMEN

Yemen occupies an area of approximately 555,000 km^2 (not including the Rub'a Al-Khali and the Islands) in the southernmost tip of the Arabian peninsula. The country's population reached 25.4 million in 2013 with a population growth rate of 2.5% (CIA 2013).

Yemen depends almost entirely on rainwater and groundwater, and limited access to water is one of the major obstacles to agriculture and development in general. Precipitation in all parts of the nation is between 67.11 billion MC (cubic meters) and 93 billion MC per year (MAI 2011). In 2010, the cultivated land reached 1.37 million ha. Of this, approximately 420,000 ha is irrigated through groundwater. About 136,335 ha is watered through surges and floodwaters. Rain-fed agricultural land accounted for 695,388 ha (MAI 2011).

Highlands that depend on groundwater are encountering rapid and dramatic decreases in the water table, and conflict over this lessening asset is growing. The rate of groundwater pumping has led to a decreasing water level in the bowls by about 1-4 meters every year (and in some bowls decline up to 7 meters each year).

CROPS

Numerous crops fare well with Yemen's precipitation patterns, including coffee, qat, and cereals such as wheatmillet and sorghum.

Table 5: Production and Potential for Cereals, Legumes, and Fodder

Item	Area [000s ha]	Production [000s tons]	Yield [Tons/ha]
Sorghum	360	375	1
Maize	32	47	1.5
Millet	103	65	0.6
Wheat	87	141	1.6
Barley	37	42	1.0
Total	**619**	**670**	**1.2**
Grasses	18	235	13
Sorghum fodder	72	977	13.6
Lucerne	26	237	9.0
Total	**116**	**1449**	**11.9**
Qat	103	108	1
Coffee	33	11	0.4
Sesame	32	18	0.6
Cotton	27	27	1.0
Tobacco	5	11	2,2
Total	**200**	**175**	**1.0**
Pulses	51	63	1.2
Vegetables and Melons	65	775	11.9
Fruits	91	590	6.5
Total	**207**	**1428**	**6.5**
Grand Total	**1,142**	-	

Source: Agricultural Statistics Year Book (MAI 2000)

SOIL

Yemen can be divided topographically into the coastal plain, the highlands, the western slopes and the eastern plains. Each of these have different soil types (FAO 2001):

- In the coastal plains and *wadis*, soils are either alluvial or coarse inter-*wadi* soils. In the flood plains the soils are loamy to silt and clay, which is adequately fertile for agricultural activities. In between the flood plains are mostly dune formations and coarse skeletal sandy soils.
- The highlands include regions between mountains which have mostly loamy and silty soils. There is also a small amount of clay soil that is rich in humus. These soils are very good for agricultural activities and are very fertile.
- The western slopes have spans of bare rock as well as shallow soils near the mountain peaks. The soils are stony and calcareous, with low fertility (high pH and low organic matter). The lower slopes have more silty and loamy soils suitable for agriculture.
- The eastern plains are flood plains with deep alluvial soils. Areas which are prone to flooding tend to have stratified sandy loams and silt loams.

CLIMATE CHANGE

Yemen is particularly vulnerable to climate change and climate variability due to its water scarcity and growing water demand. However, climate change could have positive impacts for Yemen. According to the Climate Change Impact Assessment on the Agriculture and Water Sectors, (World Bank 2010) precipitation could increase by 45% by 2100. There could be an increased risk of floods, but there is large variability in expected rainfall trends.

What is more certain is that there will be an increase in temperature. There are three anticipated scenarios:

- Increase in temperature between 2 and 4.5°C
- Increase in temperature between 1.6 and 3.1°C
- Increase in temperature between 1 and 1.6°C

An expected increase in precipitation is likely only if the rise in temperature remains below 1.6°C. .

CASE STUDIES

EGYPT CASE STUDY

The Tanta area was selected as this paper's Egyptian locus of study. Tanta is located 94 km north of Cairo and 130 km southeast of Alexandria. It is the capital of the Gharbia Governorate in the Nile Delta. The average annual rainfall is about 50 mm and the mean daily temperature ranges between 6.5 to 33.5°C.

The three crops selected from the Tanta area for this study were wheat, maize, and rice.

JORDAN CASE STUDY

The Mafraq governorate was selected as the Hashemite Kingdom of Jordan's focus area. Mafraq is located in north-eastern Jordan about 80 km to the north of Amman. It is part of the Badia zone that includes arid and semi-arid areas where the annual rainfall is below 200 mm and the mean daily temperature ranges between 8.7 to 25.2°C.

The three crops selected from Mafraq for this study were wheat, barley, and sorghum.

YEMEN CASE STUDY

The Sana'a area was selected as Yemen's focus area. Sana'a is located in the western part of the country about 160 km east of the Red Sea. It receives between 150–500 mm of rainfall a year with a wide variance. About 50% of its annual rainfall comes during July and August.

The three crops selected from Sana'a for this study were wheat, maize, and sorghum.

CROP SELECTION IN CASE STUDY COUNTRIES

The case study countries, Egypt, Jordan and Yemen, are interesting to compare because although they have overlapping crop mixes their irrigation patterns are slightly different. While Egypt relies on irrigation, Yemen relies mostly on rain-fed agriculture. Jordan has a mix between rain-fed and irrigated agriculture. Table 6 shows the crops selected in each country, the reason for selection and the geographic location.

Table 6: Crop Selection in Case Study Countries

Country	Selected Crops	Reason for Selection	Locations to be Examined (for soil and climate data)
Egypt	Rice, Maize, and Wheat	Main crops with the largest harvested area that contribute to food security	Tanta, North Delta
Jordan	Wheat, and Barley and Sorghum	Main crops with the largest harvested area that contribute to food security	Mafraq
Yemen	Sorghum, Maize, and Wheat	Main crops with the largest harvested area, that contribute to food security	Sana'a

The model methodology is illustrated in Figure 2 below. The climate parameters entered into the model were based on selected climate change scenarios. These and the crop types for each country were used by the CROPWAT model to produce the expected changes in crop yield and water use. This can then be used in policy evaluation and planning.

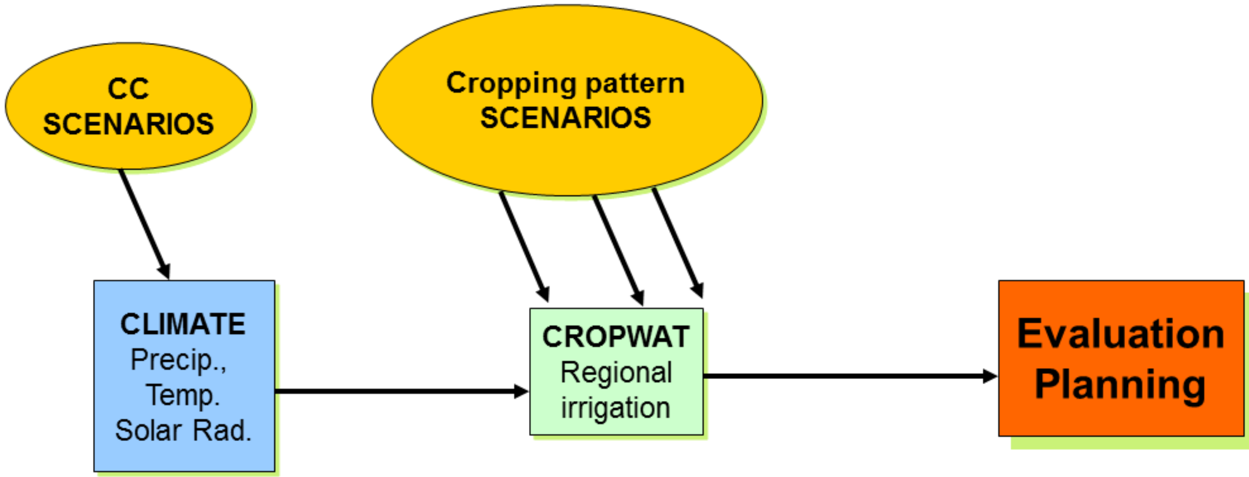
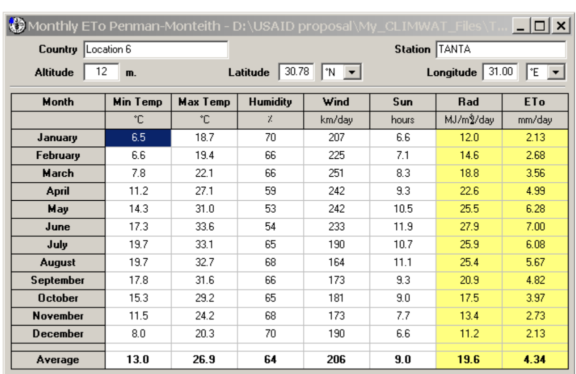


Figure 2: Modeling Methodology Used

MODEL DATA INPUT

CLIMATE/ETO DATA

CROPWAT requires information on the meteorological station (country, name, altitude, latitude, and longitude) together with climatic data (temperature, minimum and maximum), humidity, wind speed, and sun hours. CROPWAT calculates the radiation and evapotranspiration (ETo) using the FAO Penman-Monteith approach. Climate/ETo module data is shown in Figures 3, 4, and 5.



Monthly ETo Penman-Monteith - D:\USAID proposal\My_CLIMWAT_Files\T...

Country Location 6 Station TANTA

Altitude 12 m. Latitude 30.78 °N Longitude 31.00 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.5	18.7	70	207	6.6	12.0	2.13
February	6.6	19.4	66	225	7.1	14.6	2.68
March	7.8	22.1	66	251	8.3	18.8	3.56
April	11.2	27.1	59	242	9.3	22.6	4.99
May	14.3	31.0	53	242	10.5	25.5	6.28
June	17.3	33.6	54	233	11.9	27.9	7.00
July	19.7	33.1	65	190	10.7	25.9	6.08
August	19.7	32.7	68	164	11.1	25.4	5.67
September	17.8	31.6	66	173	9.3	20.9	4.82
October	15.3	29.2	65	181	9.0	17.5	3.97
November	11.5	24.2	68	173	7.7	13.4	2.73
December	8.0	20.3	70	190	6.6	11.2	2.13
Average	**13.0**	**26.9**	**64**	**206**	**9.0**	**19.6**	**4.34**

Figure 3: Climate/ETo Module data in Tanta

Monthly ETo Penman-Monteith - C:\Users\AM\Desktop\CEDARE\Mafraq\Scenario1\Best Scen...

Country: Location 20 Station: MAFRAQ

Altitude: 687 m. Latitude: 32.36 °N Longitude: 36.25 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	2.9	13.8	70	242	4.5	9.4	1.74
February	3.9	15.8	66	216	5.8	12.7	2.22
March	5.9	19.1	62	233	5.7	15.1	3.04
April	9.1	23.9	52	207	7.7	20.0	4.36
May	12.3	29.2	45	190	9.4	23.8	5.66
June	15.1	32.7	46	259	11.4	27.1	7.21
July	16.4	33.7	52	302	11.4	26.8	7.43
August	16.6	33.8	55	268	11.0	25.1	6.80
September	14.1	31.8	53	225	9.8	21.2	5.61
October	11.6	27.2	51	181	8.0	15.9	3.97
November	7.3	21.5	55	199	6.7	12.0	2.87
December	3.1	15.3	67	251	4.7	9.0	1.95
Average	9.9	24.8	56	231	8.0	18.2	4.40

Figure 4: Climate/ETo Module data in Mafraq

Monthly ETo Penman-Monteith - D:\USAID proposal\My_CLIMWAT_Files\S...

Country: Location 7 Station: SANA_A

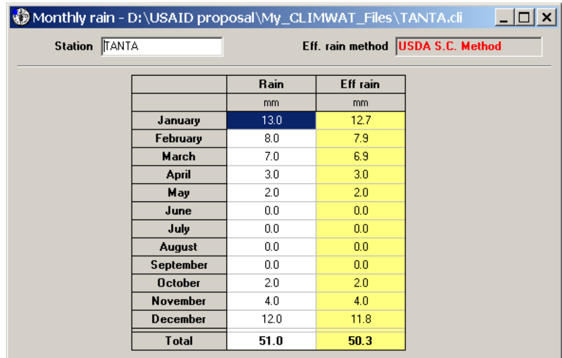
Altitude: 2190 m. Latitude: 15.51 °N Longitude: 44.18 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	2.6	23.4	35	173	7.5	17.1	3.92
February	4.9	25.1	37	190	7.5	18.6	4.49
March	6.3	26.6	34	190	6.7	19.0	4.95
April	8.5	25.4	43	173	7.7	21.3	4.88
May	9.1	27.4	34	190	7.3	20.8	5.38
June	10.1	29.5	28	233	7.8	21.2	6.22
July	11.4	29.1	33	207	5.7	18.1	5.51
August	11.7	28.0	45	199	6.7	19.6	5.21
September	8.5	27.2	32	225	7.5	20.3	5.66
October	4.3	25.1	31	164	7.9	19.5	4.64
November	2.7	22.9	40	130	8.1	18.2	3.65
December	2.5	22.2	38	156	7.0	15.9	3.51
Average	6.9	26.0	36	186	7.3	19.1	4.83

Figure 5: Climate/ETo Module data in Sana'a

RAINFALL DATA

CROPWAT requires information about the average rainfall at the selected station. In this study the USDA S.C. method is chosen to calculate the effective rainfall. This is particularly appropriate for areas with low rainfall and high soil infiltration which is generally the case in the study areas (FAO 1978). Rainfall Data Module is shown in Figures 6, 7, and 8.

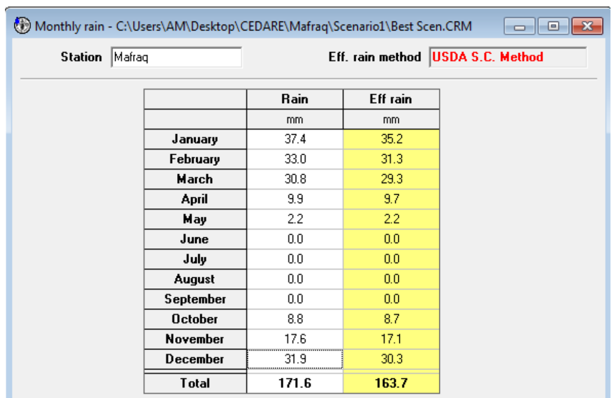


Monthly rain - D:\USAID proposal\My_CLIMWAT_Files\TANTA.cli

Station TANTA Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	13.0	12.7
February	8.0	7.9
March	7.0	6.9
April	3.0	3.0
May	2.0	2.0
June	0.0	0.0
July	0.0	0.0
August	0.0	0.0
September	0.0	0.0
October	2.0	2.0
November	4.0	4.0
December	12.0	11.8
Total	51.0	50.3

Figure 6: Rainfall Module data in Tanta

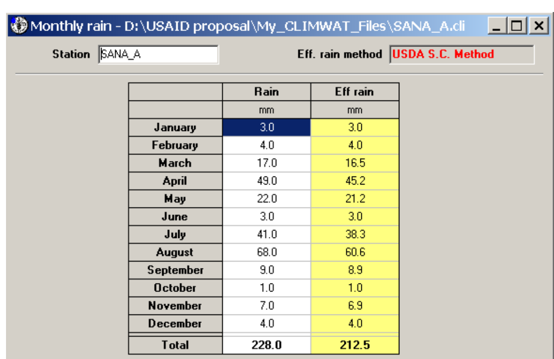


Monthly rain - C:\Users\AM\Desktop\CEDARE\Mafraq\Scenario1\Best Scen.CRM

Station Mafraq Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	37.4	35.2
February	33.0	31.3
March	30.8	29.3
April	9.9	9.7
May	2.2	2.2
June	0.0	0.0
July	0.0	0.0
August	0.0	0.0
September	0.0	0.0
October	8.8	8.7
November	17.6	17.1
December	31.9	30.3
Total	171.6	163.7

Figure 7: Rainfall Module data in Mafraq



Monthly rain - D:\USAID proposal\My_CLIMWAT_Files\SANA_A.cli

Station SANA_A Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	3.0	3.0
February	4.0	4.0
March	17.0	16.5
April	49.0	45.2
May	22.0	21.2
June	3.0	3.0
July	41.0	38.3
August	68.0	60.6
September	9.0	8.9
October	1.0	1.0
November	7.0	6.9
December	4.0	4.0
Total	228.0	212.5

Figure 8: Rainfall Module data in Sana'a

CROP DATA

CROPWAT requires the following information about selected crops:

- Crop planting date
- Length of individual growth stages
- Crop factors, including crop evapotranspiration
- Evapotranspiration
- Rooting depth
- Allowable depletion levels
- Yield response factors

CROPWAT has crop data for several common crops taken from selected FAO publications, which is used in this study. Crop data modules for the selected crops in this study (wheat, maize, barley, sorghum, and rice) are shown in Annex I.

SOIL DATA

CROPWAT requires the following general soil information:

- Total available water (TAW)
- Maximum infiltration rate
- Maximum rooting depth
- Initial soil moisture depletion

Soil data module for Tanta, Mafraq, and Sana'a are shown in Figures 9, 10, and 11.

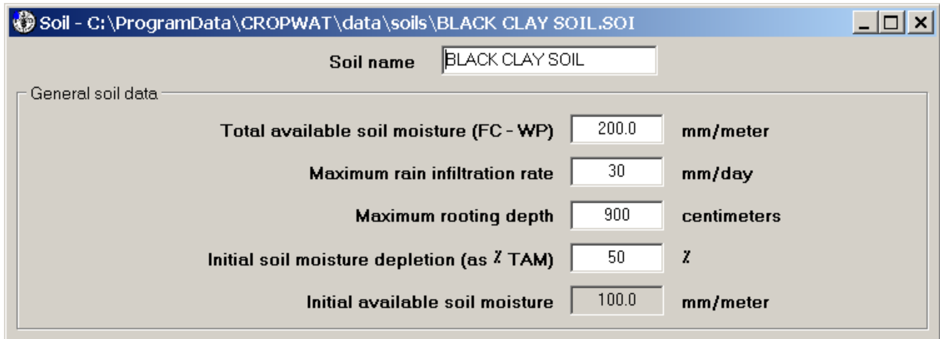


Figure 9: Soil Module Data for Tanta

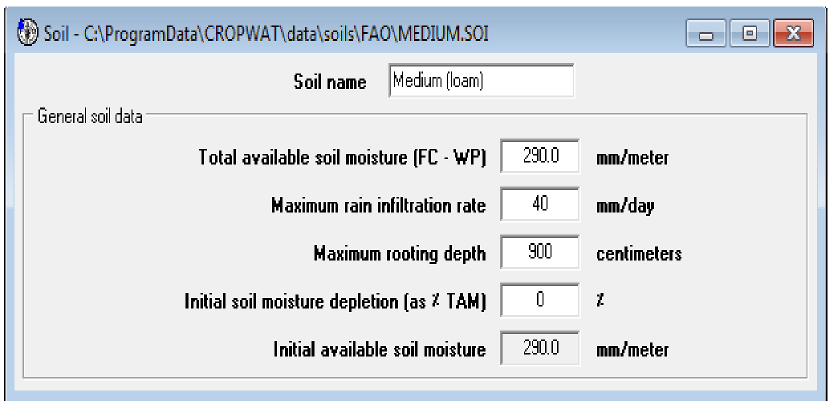


Figure 10: Soil Module Data for Mafraq

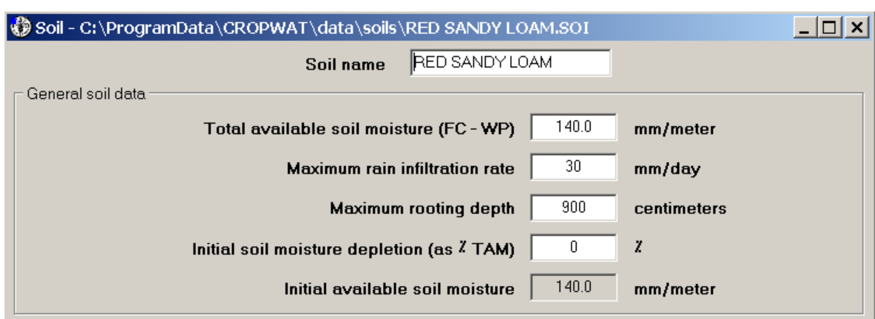


Figure 11: Soil Module Data for Sana’a

ANTICIPATED CLIMATE SCENARIOS

Four climate change scenarios were selected for study:

- **Scenario One (SC1):** In this scenario, the precipitation is assumed to have +10% increases and the temperature is assumed to have a +1 ºC increase.
- **Scenario Two (SC2):** In this scenario, the precipitation is assumed to have -20% decreases and the temperature is assumed to have a +3 ºC increase. (The Worst Scenario)
- **Scenario Three (SC3):** In this scenario, the precipitation is assumed to have -10% decreases and the temperature is assumed to have a +1 ºC increase.
- **Scenario Four (SC4):** In this scenario, no change is assumed for precipitation and the temperature is assumed to have a +2 ºC increase.

MODEL ANALYSIS AND RESULTS

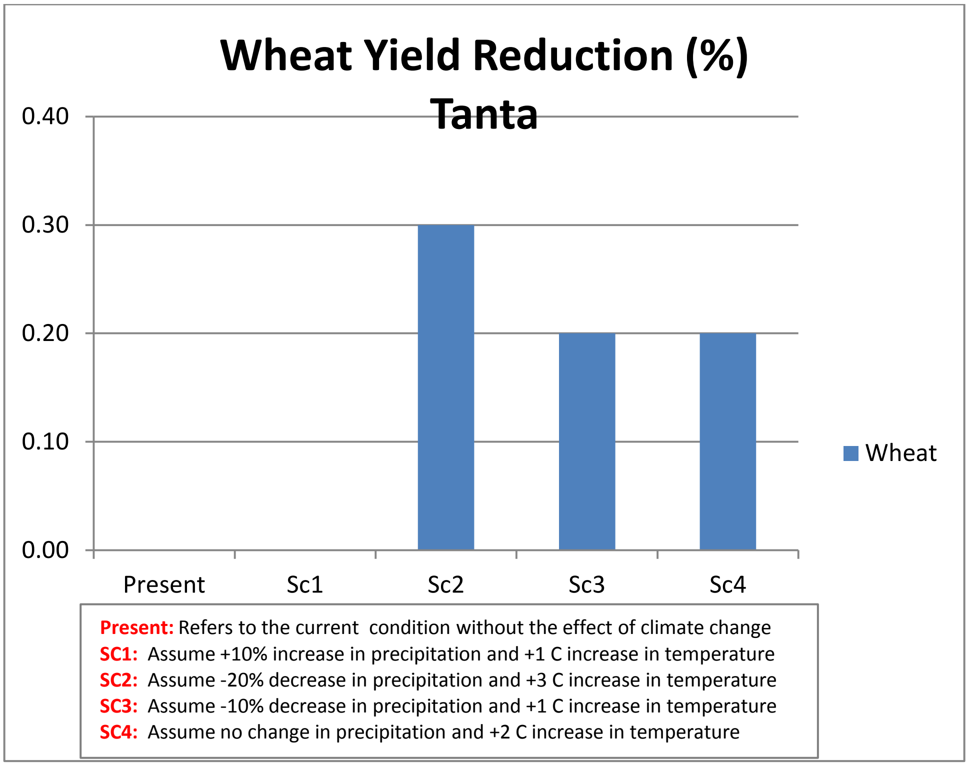
EGYPT

MODEL RESULTS FOR WHEAT

CROP YIELD REDUCTION

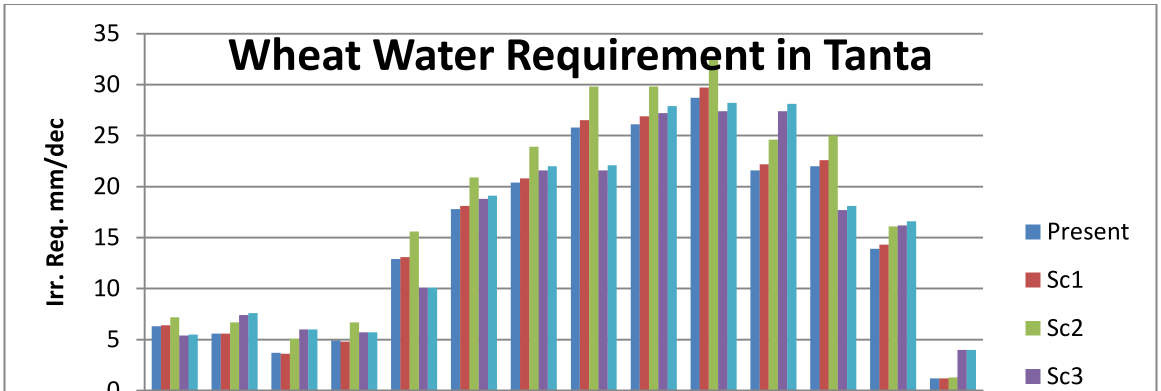
The results show that wheat yield in Tanta is not sensitive to climate change under scenario 1; the maximum yield reduction (0.3%) occurs under the SC2. Scenarios three and four lead to the same reduction in yield (0.2%). The results summarized in Figure 12 suggest that an increase in temperature has a greater (negative) effect on yield than a decrease in precipitation.

Figure 12: Expected Wheat yield Reduction in Tanta



CROP WATER REQUIREMENT

Figure 13 shows that the crop water requirement (CWR) for wheat is projected to increase during all months of the growing season as a result of climate change scenarios compared to the current condition without climate change (present).



	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar	Mar	Mar
Present	6.3	5.6	3.7	4.9	12.9	17.8	20.4	25.8	26.1	28.7	21.6	22	13.9	1.2
Sc1	6.4	5.6	3.6	4.8	13.1	18.1	20.8	26.5	26.9	29.7	22.2	22.6	14.3	1.2
Sc2	7.2	6.7	5.1	6.7	15.6	20.9	23.9	29.8	29.8	32.6	24.6	25	16.1	1.3
Sc3	5.4	7.4	6	5.7	10.1	18.8	21.6	21.6	27.2	27.4	27.4	17.7	16.2	4
Sc4	5.5	7.6	6	5.7	10.1	19.1	22	22.1	27.9	28.2	28.1	18.1	16.6	4

Figure 13: Expected Monthly Crop Water Requirements (CWR) for Wheat in Tanta

*Water requirement is calculated for every 10 days

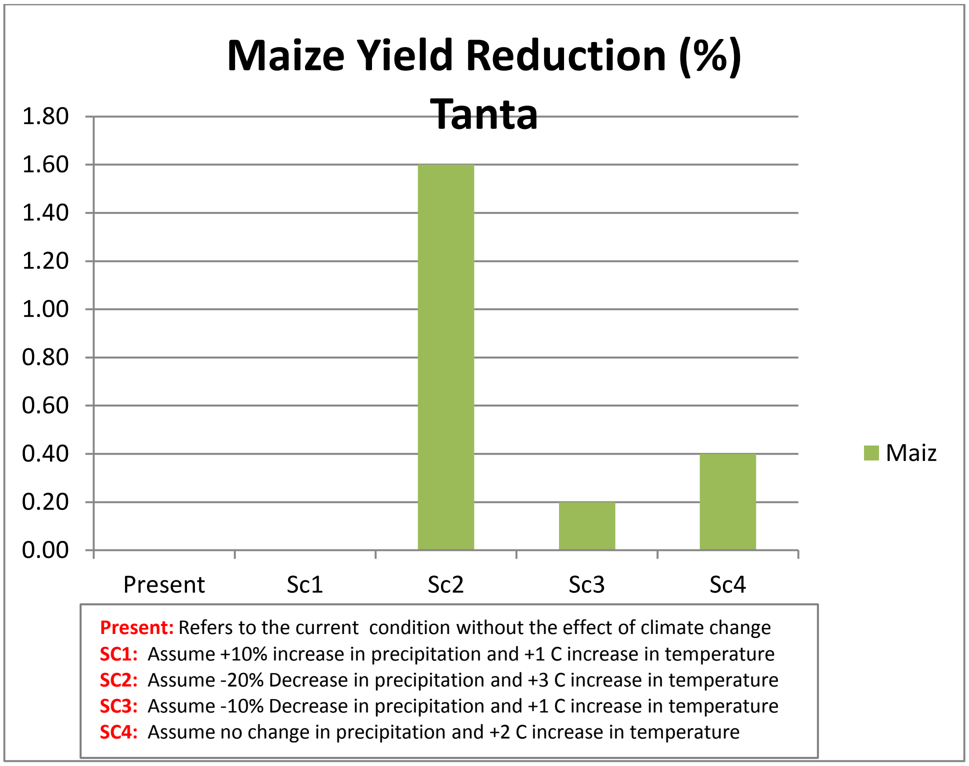


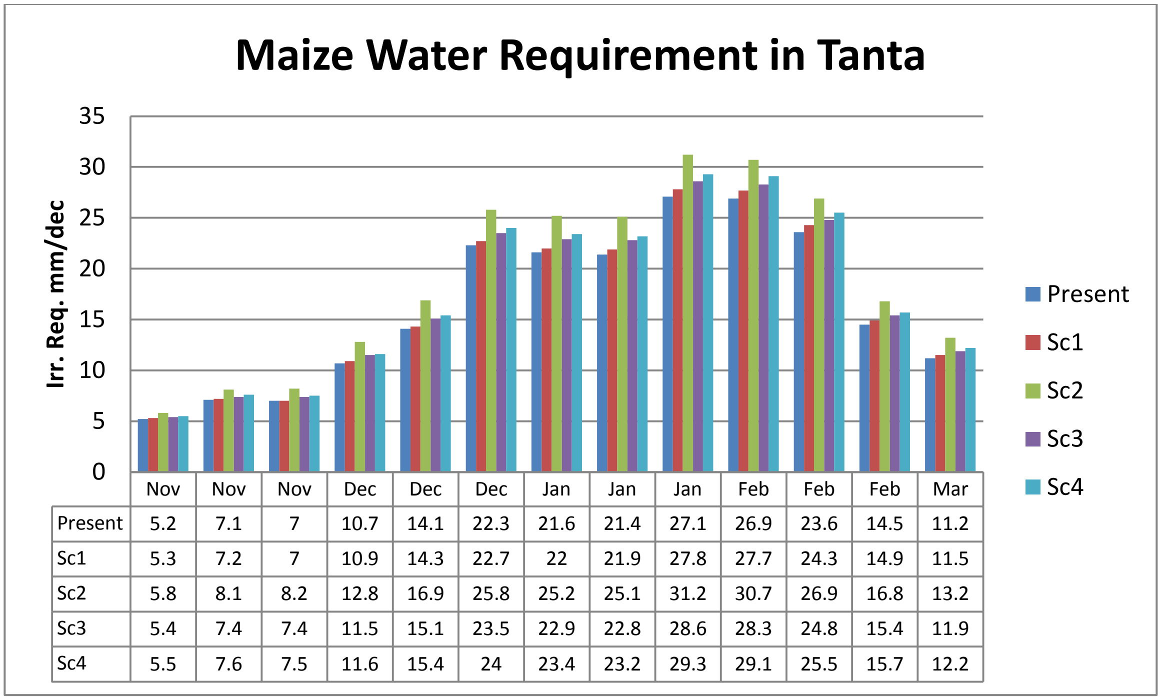
Figure 14: Expected Maize Yield Reduction in Tanta

CROP YIELD REDUCTION

The results from the model show that maize yield is very sensitive to climate change under scenario 2, even more so than wheat. The maize yield is projected to decrease by 1.6%. Like wheat, an increase in temperature has a greater impact on yield reduction than reduced precipitation.

CROP WATER REQUIREMENT

Figure 15 shows that the crop water requirement (CWR) for barley is projected to increase during all months of the growing season under scenario 2. Under scenarios 1, 3 and 4 water requirements will increase to a lesser extent or stay the same.



	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar
Present	5.2	7.1	7	10.7	14.1	22.3	21.6	21.4	27.1	26.9	23.6	14.5	11.2
Sc1	5.3	7.2	7	10.9	14.3	22.7	22	21.9	27.8	27.7	24.3	14.9	11.5
Sc2	5.8	8.1	8.2	12.8	16.9	25.8	25.2	25.1	31.2	30.7	26.9	16.8	13.2
Sc3	5.4	7.4	7.4	11.5	15.1	23.5	22.9	22.8	28.6	28.3	24.8	15.4	11.9
Sc4	5.5	7.6	7.5	11.6	15.4	24	23.4	23.2	29.3	29.1	25.5	15.7	12.2

Figure 15: Expected Monthly Crop Water Requirements (CWR) for Maize in Tanta

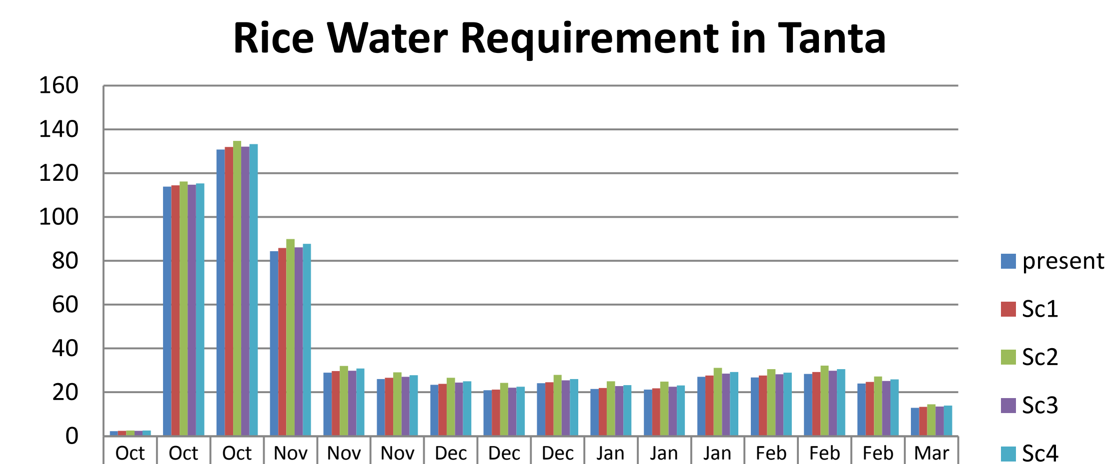
*Water requirement is calculated for every 10 days

MODEL RESULT FOR RICE

CROP YIELD REDUCTION

The results from the model show that rice yield in Tanta is not affected by climate change scenarios because rice requires large amounts of water and depends mainly on irrigation. There is zero change in yield under any climate change scenario.

Figure 16 shows that the crop water requirement (CWR) for rice is projected to increase during all months of the growing season as a result of climate change scenarios compared to the current condition without climate change (present) especially under SC2 (The Worst Scenario).



	Oct	Oct	Oct	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar
present	2.3	113.9	130.8	84.4	29	26	23.4	20.9	24.1	21.5	21.3	27	26.8	28.4	24	12.9
Sc1	2.4	114.5	131.9	85.8	29.7	26.6	23.9	21.3	24.6	21.9	21.8	27.7	27.6	29.3	24.7	13.3
Sc2	2.6	116.2	134.7	89.9	32	29.1	26.7	24.3	27.9	25	24.9	31.1	30.6	32.2	27.2	14.6
Sc3	2.4	114.7	132.1	86.2	29.9	27	24.5	22.1	25.4	22.8	22.6	28.5	28.2	29.8	25.2	13.5
Sc4	2.5	115.3	133.3	87.8	30.8	27.8	25.1	22.6	26	23.3	23.1	29.2	29	30.6	25.9	13.9

Figure 16: Expected Monthly Crop Water Requirements (CWR) for Rice

*Water requirement is calculated for every 10 days

MODEL RESULTS FOR WHEAT

CROP YIELD REDUCTION

The results show that winter wheat is very sensitive to climate change and yield is projected to decrease under all climate change scenarios; the maximum yield reduction (6.6%) occurs at the SC2. The increasing temperature reduces yields more than decreasing precipitation in the results from SC3 and SC4 in Figure 17.

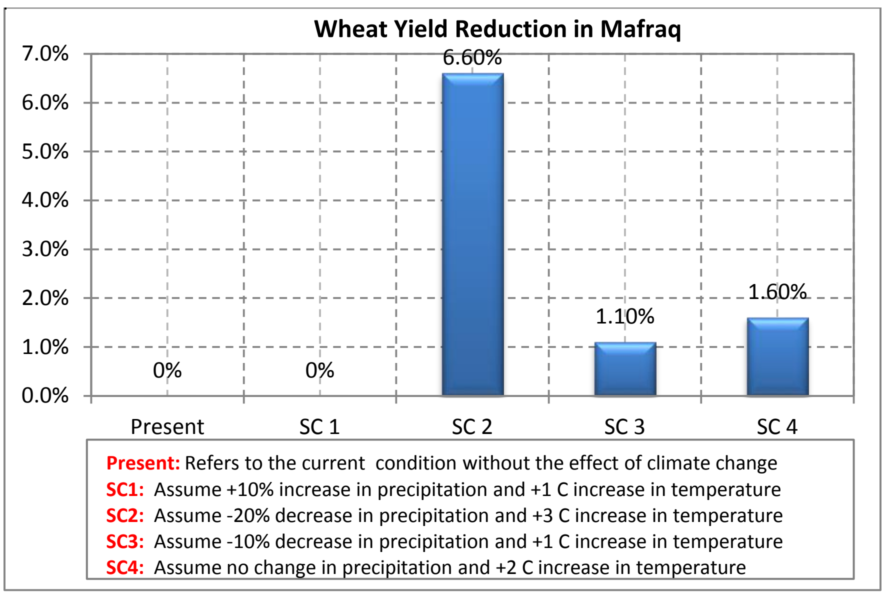
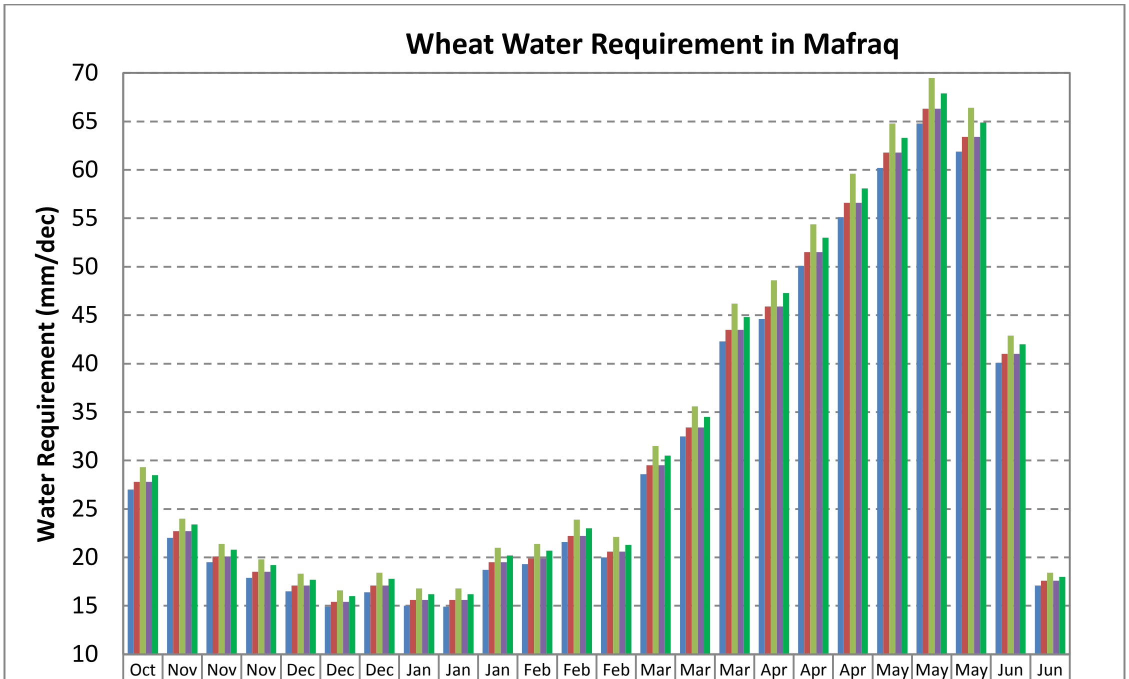


Figure 17: Expected Wheat Yield Reduction in Mafraq

CROP WATER REQUIREMENT

Figure 18 shows that the crop water requirement (CWR) for wheat is projected to increase during all months of the growing season as a result of climate change scenarios compared to the current condition without climate change (present).



	Oct	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar	Mar	Mar	Apr	Apr	Apr	May	May	May	Jun	Jun
Present	27	22	19.5	17.9	16.5	14.9	16.4	15	14.9	18.7	19.3	21.6	20	28.6	32.5	42.3	44.6	50.1	55.1	60.2	64.8	61.9	40.1	17.1
SC1	27.8	22.7	20.1	18.5	17.1	15.4	17.1	15.6	15.6	19.5	19.9	22.2	20.6	29.5	33.4	43.5	45.9	51.5	56.6	61.8	66.3	63.4	41	17.6
SC2	29.3	24	21.4	19.8	18.3	16.6	18.4	16.8	16.8	21	21.4	23.9	22.1	31.5	35.6	46.2	48.6	54.4	59.6	64.8	69.5	66.4	42.9	18.4
SC3	27.8	22.7	20.1	18.5	17.1	15.4	17.1	15.6	15.6	19.5	19.9	22.2	20.6	29.5	33.4	43.5	45.9	51.5	56.6	61.8	66.3	63.4	41	17.6
SC4	28.5	23.4	20.8	19.2	17.7	16	17.8	16.2	16.2	20.2	20.7	23	21.3	30.5	34.5	44.8	47.3	53	58.1	63.3	67.9	64.9	42	18

Figure 18: Expected Monthly Crop Water Requirements (CWR) for Wheat in Mafraq

*Water requirement is calculated for every 10 days

.

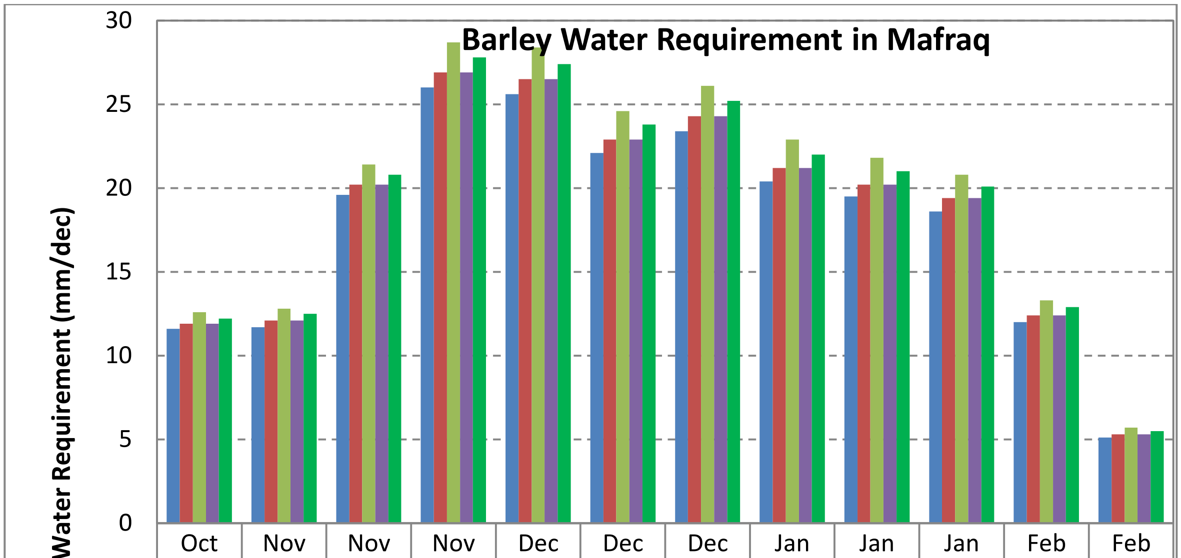
MODEL RESULT FOR BARLEY

CROP YIELD REDUCTION

The results from the model show that barley yield is not affected by any of the climate change scenarios. Adaptation plans should prioritize barley cultivation in this area.

CROP WATER REQUIREMENT

Figure 19 shows that the crop water requirement (CWR) for barley is projected to increase during all months of the growing season as a result of climate change scenarios compared to the current condition without climate change (present).



	Oct	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb
Present	11.6	11.7	19.6	26	25.6	22.1	23.4	20.4	19.5	18.6	12	5.1
SC1	11.9	12.1	20.2	26.9	26.5	22.9	24.3	21.2	20.2	19.4	12.4	5.3
SC2	12.6	12.8	21.4	28.7	28.4	24.6	26.1	22.9	21.8	20.8	13.3	5.7
SC3	11.9	12.1	20.2	26.9	26.5	22.9	24.3	21.2	20.2	19.4	12.4	5.3
SC4	12.2	12.5	20.8	27.8	27.4	23.8	25.2	22	21	20.1	12.9	5.5

Figure 19: Expected Monthly Crop Water Requirements (CWR) for Barley in Mafraq

*Water requirement is calculated for every 10 days

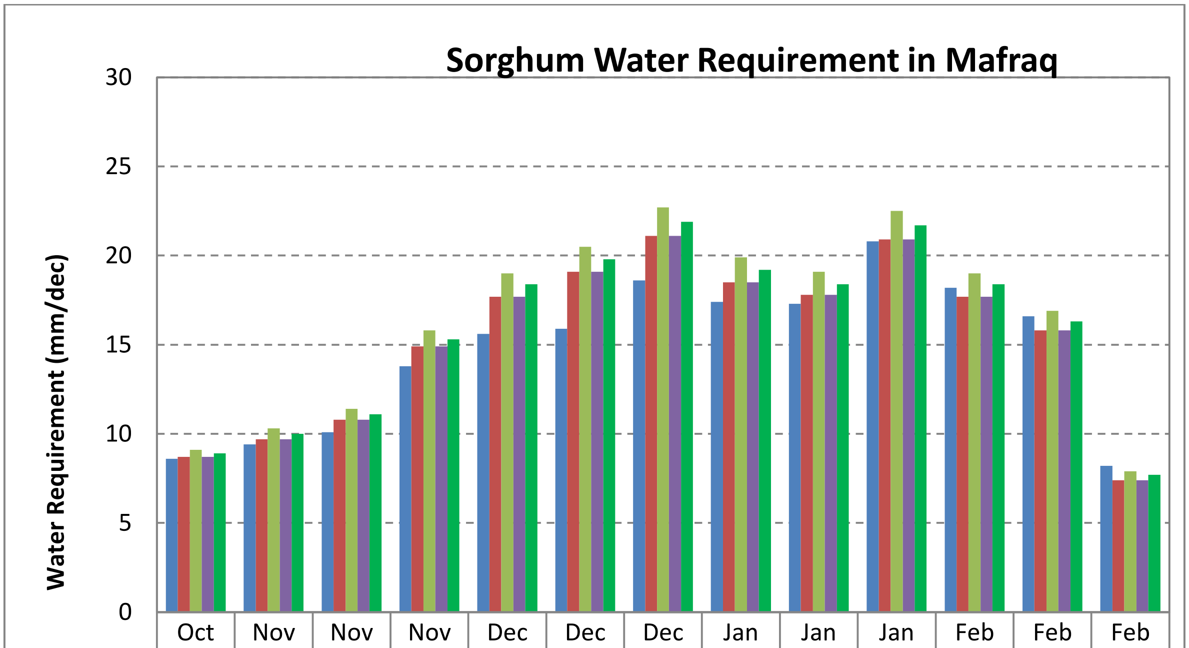
MODEL RESULT FOR SORGHUM

CROP YIELD REDUCTION

The results from the model show that sorghum yield is not affected by any of the climate change scenarios. Adaptation plans should prioritize sorghum cultivation in this area.

CROP WATER REQUIREMENT

Figure 20 shows that the crop water requirement (CWR) for sorghum is projected to increase during all months of the growing season as a result of climate change scenarios compared to the current condition without climate change (present) except in the late stage of the growing season (February) where the crop water requirement is projected to decrease for the four scenarios.



	Oct	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb
Present	8.6	9.4	10.1	13.8	15.6	15.9	18.6	17.4	17.3	20.8	18.2	16.6	8.2
SC1	8.7	9.7	10.8	14.9	17.7	19.1	21.1	18.5	17.8	20.9	17.7	15.8	7.4
SC2	9.1	10.3	11.4	15.8	19	20.5	22.7	19.9	19.1	22.5	19	16.9	7.9
SC3	8.7	9.7	10.8	14.9	17.7	19.1	21.1	18.5	17.8	20.9	17.7	15.8	7.4
SC4	8.9	10	11.1	15.3	18.4	19.8	21.9	19.2	18.4	21.7	18.4	16.3	7.7

Figure 20: Expected Monthly Crop Water Requirements (CWR) for Sorghum in Mafraq

*Water requirement is calculated for every 10 days

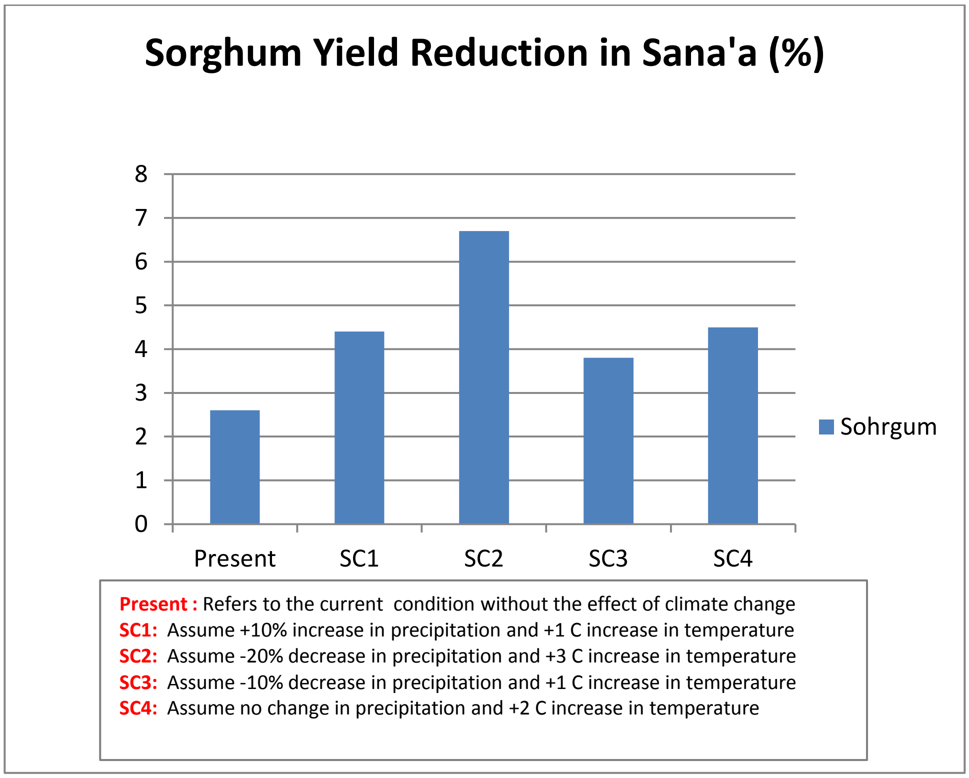
YEMEN

The suggested four climate change scenarios and the scenario that represent the current condition without the effect of climate change were applied in the CROPWAT model for sorghum, wheat and barley in Sana’a, Yemen. The Yemeni case study was different than the others, as the selected crops are dependent on rain, not irrigation. Thus, crop water requirement is charted by season rather than month.

MODEL RESULTS FOR SORGHUM

CROP YIELD REDUCTION

The sorghum yield was less affected by climate change scenarios than wheat. The maximum yield reduction (6.7%) occurred at SC2. However, a 2.6% reduction is expected under the present conditions, due to sorghum requiring more water than current rainfall provides.



n

Figure 21: Expected Sorghum Yield Reduction in Sana'a

CROP WATER REQUIREMENT

Figure 22 shows the crop water requirement (CWR) for Sorghum in Sana'a. The maximum CWR occurred at SC2.

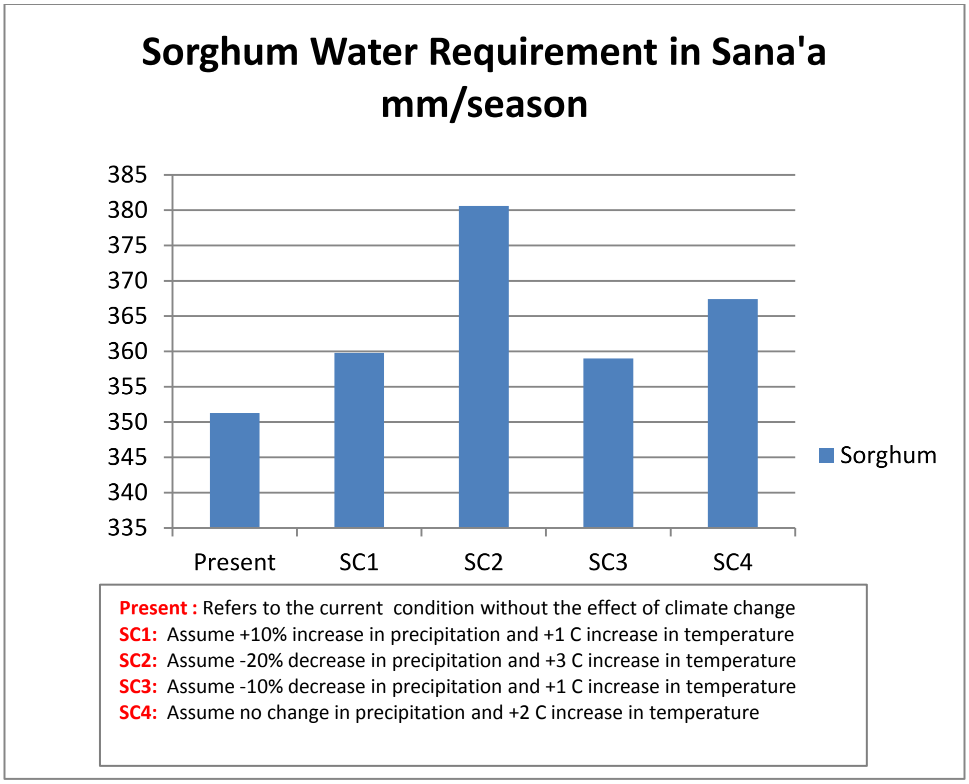


Figure 22: Expected Crop Water Requirements (CWR) for Sorghum in Sana'a

MODEL RESULTS FOR WHEAT

CROP YIELD REDUCTION

The results show that wheat is very sensitive to climate change. The maximum yield reductions are estimated at 20.7% for wheat at SC2. The yield reductions for wheat are estimated at 14% under the current climate conditions due to the already low water supplies and sub-optimal production levels.

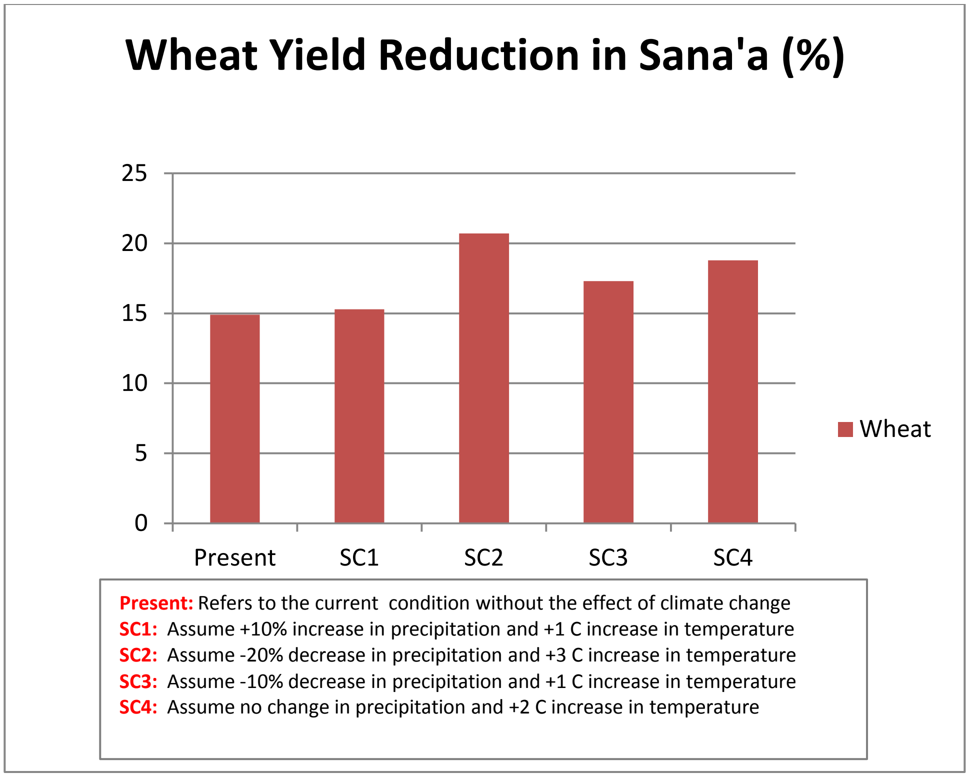


Figure 23: Expected Wheat Yield Reduction in Sana'a

CROP WATER REQUIREMENT

Figure 24 shows the crop water requirement (CWR) for wheat in Sana'a. The maximum CWR is at SC2. The CWR for wheat and barley are very similar.

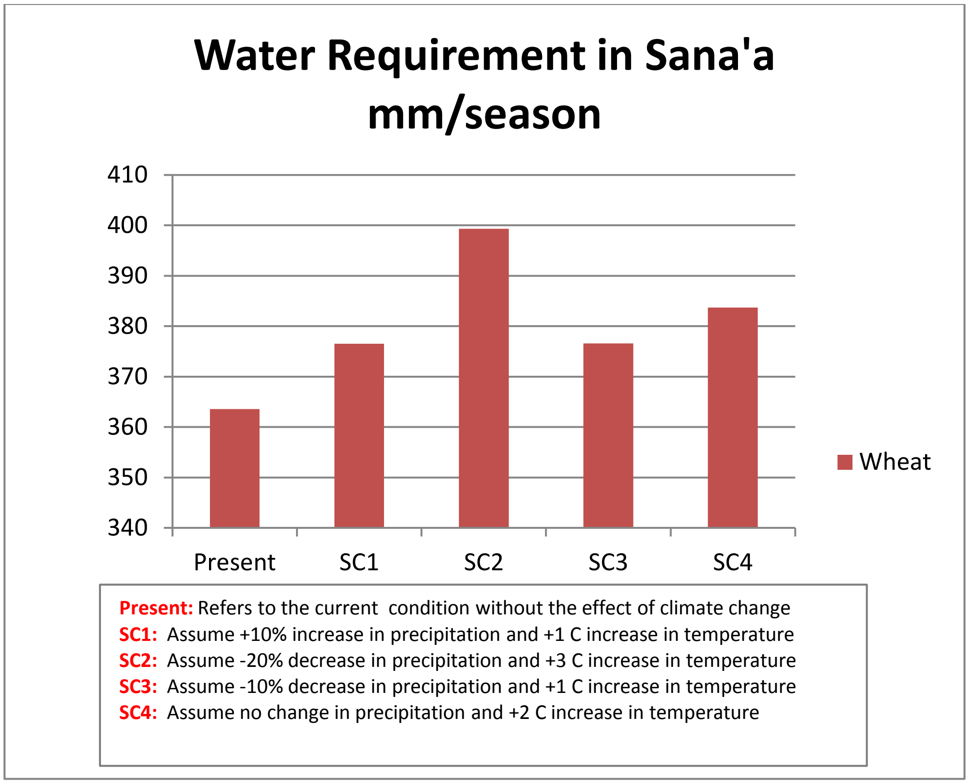


Figure 24: Expected Crop Water Requirement (CWR) for Wheat in Sana'a

MODEL RESULTS FOR BARLEY

CROP YIELD REDUCTION

The results show that barley is very sensitive to climate change. The maximum yield reductions are estimated at 21.8% at SC2. Yield reductions are estimated at 16.2% under current climate conditions.

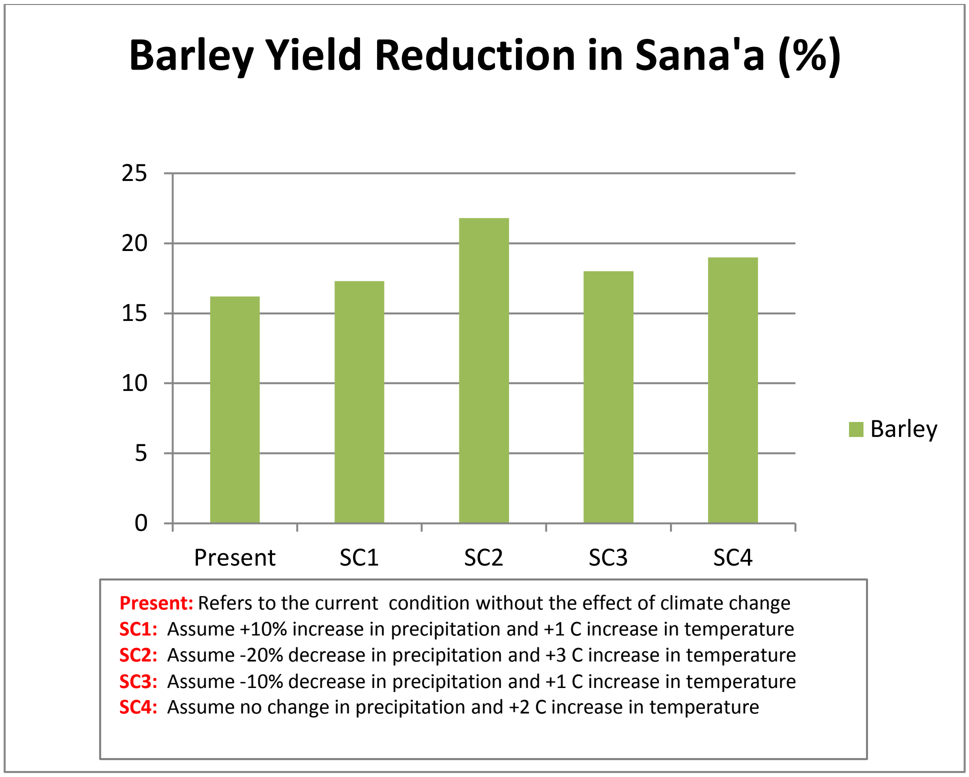


Figure 25: Expected Barley Yield Reduction in Sana'a

CROP WATER REQUIREMENT

Figure 26 shows the crop water requirement (CWR) for barley in Sana'a. The maximum CWR is at SC2. The CWR for wheat and barley are very similar.

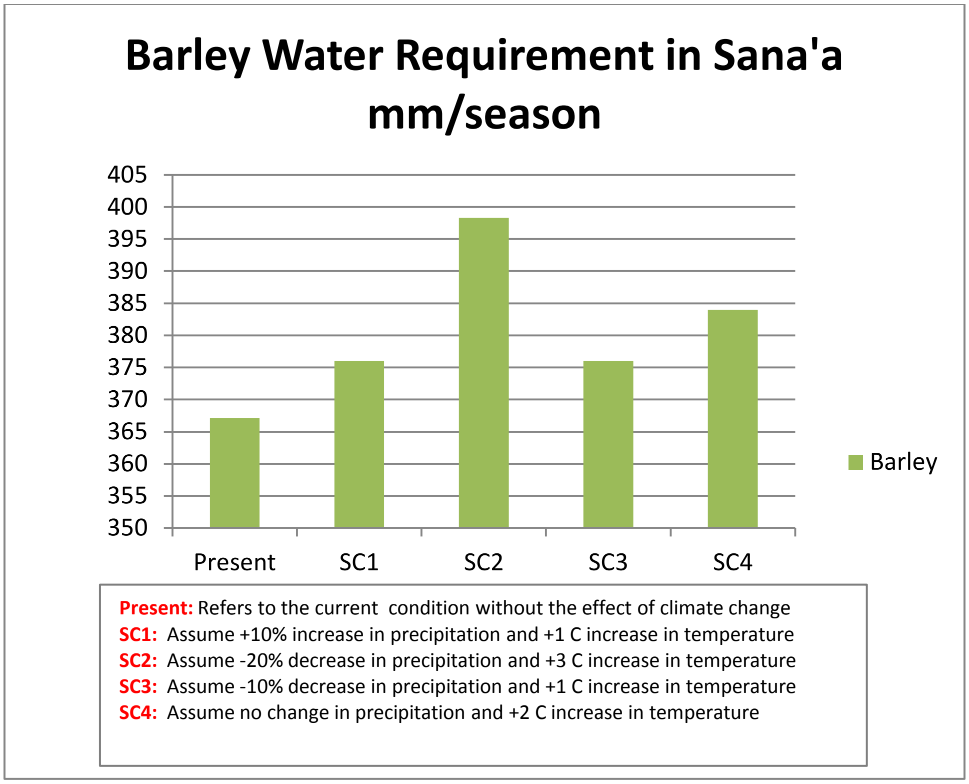


Figure 26: Expected Crop Water Requirements for Barley in Sana'a

LINKAGE AMONG CASE STUDIES

The three case studies of Egypt, Jordan, and Yemen could be considered to represent the main crop water and irrigation scenarios in the MENA region. In Egypt's case, crops depend mainly on irrigation, while in Jordan, crops use both rain-fed and supplemental irrigation. In Yemen, however, farmers depend only on rain; as a result, Yemen is the country most vulnerable to climate change. Egypt already receives very little rainfall; its location at the downstream end of the Nile means it will mostly incur a secondary effect as climate change impacts on neighboring Nile-basin countries. The findings confirm that the three chosen countries provided an interesting test of the CROPWAT model and provide a good representation of the region.

CONCLUSION AND RECOMMENDATIONS

In general, this study indicates that CROPWAT can be successfully used to assess potential impacts of climate change on cropping patterns. The model is user-friendly and simple.

Agricultural cropping patterns should be enhanced to cope with anticipated climate change. Adoption of improved agricultural practices and technologies in general will be needed to cope with the constraints imposed by future climate change.

CROPWAT is a tool Model used to have pre prediction to the impact of climate change on the agriculture pattern in the future, so it's better to use real data for climate, soil and crop that measured for the three studies countries rather than using the available data in the FAO database in order to have model results that reflect the actual values of crop water requirement and yield reduction.

The model activities in this research focus only on effects of climate change on crop water requirement. More constraints should be taken into consideration in future research including social, political, and economic aspects in optimizing the crop mix and water use.

General conclusions:

- Under any of the three scenarios of climate change, water-uptake of strategic crops will increase.
- Yields are more sensitive to temperature fluctuations than precipitation in Jordan and Egypt because the selected crops are irrigated. In Yemen the crops are much more sensitive to precipitation changes.
- Yemen is more vulnerable in general, with the rates of yield reduction being much higher than in Jordan and Egypt.
- In Egypt maize will have the greatest reduction in yield. Wheat will be the least impacted.
- In Jordan wheat will have the greatest reduction in yield. Barley and sorghum are fairly resilient to climate change and could be invested in more heavily.
- In Yemen, barley will have the greatest reduction in yield while sorghum is fairly resilient to climate change.
- Yemen’s crop yield will decrease even under present conditions due to the already low rainfall levels.

Recommendations:

- Modification of cropping pattern:
    - Egypt should avoid rice and maize because of their vulnerability. There should be a focus on less water intensive and climate resilient cash crops that can be exported like cotton.
    - Jordan should shift away from wheat and stick with barley and sorghum.
    - Yemen should shift away from wheat and barley to sorghum.
- In addition to changing cropping patterns, better water-use management is necessary. Jordan and Egypt must consider upgrading their irrigation systems to improve efficiency, and ensure that drip irrigation is used more widely. This is especially important for Egypt where many farms still use flood irrigation. Wastewater reuse is another important

resource, as more and more is generated from rural and urban areas each year. There needs to be greater attention given to the treatment and utilization of this wastewater in order to ensure that global standards are upheld in its use in agriculture.

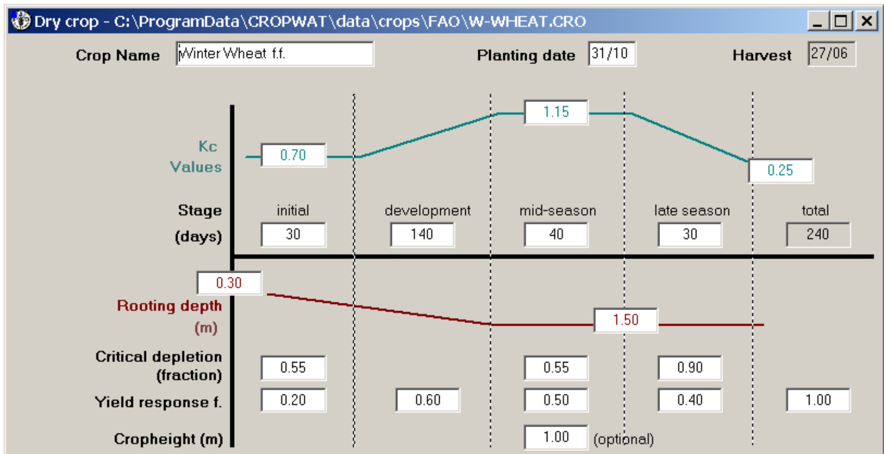
REFERENCES

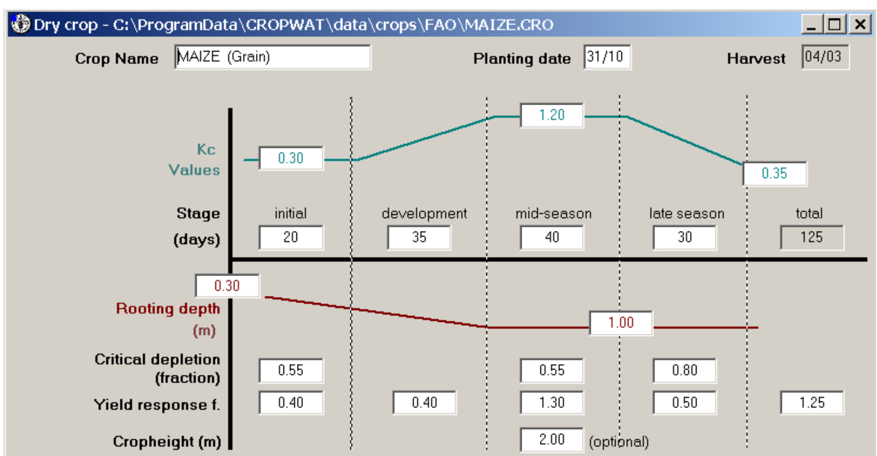
1. Al-Bakri, J.T., Salahat, M., Suleiman, M., Suifan, M., Hamdan, M.R., Khresat, S., & Kandakji, T. (2013). Impact of climate and land use change on water and food security in Jordan: implications for transcending "The tragedy of the commons." *Sustainability,* 5, 724 –748.
2. Al-Bakri, J.T., Suleiman, A., Abdulla, F., & Ayad, J. (2011). Potential impacts of climate change on the rainfed agriculture of a semi-arid basin in Jordan. *Phys. Chem. Earth*, 35, 125–134.
3. AOAD (Arab Organization for Agricultural Development). Arab Agricultural Statistics Yearbook; AOAD: Khartoum, Sudan, 1995; Volume 15.
4. Al Qudah, B. (2001). Soils of Jordan. *Soil resources of Southern and Eastern Mediterranean Countries*, 127–141
5. Agriculture and Agri-Food Canada. (2010). Agriculture, Food & Beverages Sector Profile – Amman, Jordan.
6. AREA (1997). Agricultural Research and Extension Authority, Agro-Climatic Resources of Yemen. Part 1.
7. Aly, A., Ahmed, S., & Saleh, E. (2007). Suitable Cropping Patterns for the Egyptian Desert Lands in the Context of Groundwater Limitation. *Egyptian Journal of Agricultural Economics*, 17(3), 933–947.
8. Damhoureyeh, Saeed. (2010). An overview of Azraq. Department of Ecology. Jordan University.
9. DoS. (2012). Jordan in Figures: 2011, report no. 14. Amman, Jordan.
10. DoS. (2010). Study of Households Income and Expenditures 1987–2010. Amman, Jordan.
11. DoS. (2008). Food Balance Sheet of 2008. Amman, Jordan.
12. El Sayed, L. M. Determining an optimum cropping pattern for Egypt, The American University in Cairo, 2012.
13. FAO. (2011). Egypt Country Profile.
14. FAO. (2006). Country Pasture/Forage Resource Profiles, Jordan. Rome, Italy.

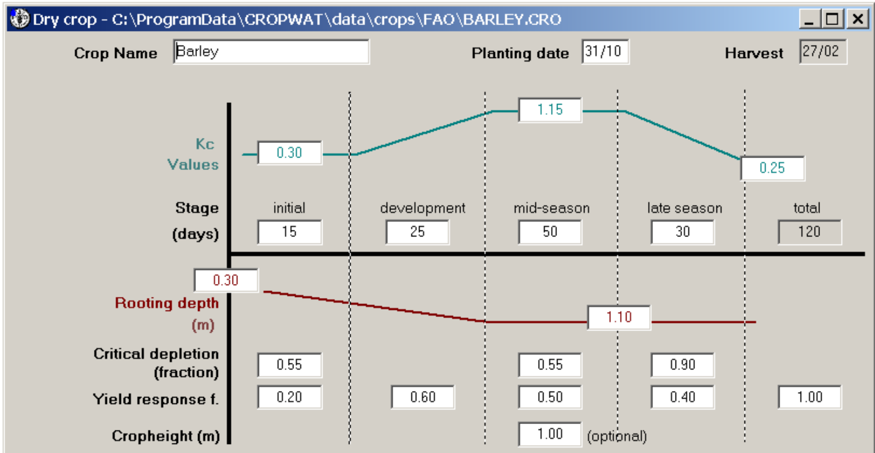
15. FAO. (2005). Fertilizer use by crop in Egypt. Land and Water Development Division. Rome, Italy.
16. FAO. (2001). Yemen Country Profile.
17. FAO. (1997). Underlying Causes of Desertification, Consultant Report. Rome, Italy.
18. FAO. (1978). Effective Rainfall in Irrigated Agriculture. Irrigation and Drainage Papers.
19. Hamdi H., & Abdelhafez S. (2001). Agriculture and Soil Survey in Egypt. *Soil resources of Southern and Eastern Mediterranean Countries*, 111–125.
20. Hanna, M. Z. "An Economic Study for the Optimal Crop Pattern in Dakahlya Governorate." (Unpublished Masters dissertation), Ain Shams University, Cairo, 1970.
21. Heady, E. (1948). The Economics of Rotations with Farm and Production Policy Applications. *Journal of Farm Economics, 30*(4), 645–664.
22. Hildreth, C., & Reiter, S. (1951). On the Choice of a Crop Rotation Plan. In T. Koopmans *Activity Analysis of Production and Allocation* (pp. 177–188). New York: John Wiley & Sons, Inc.
23. IFAD. (2012). Jordan: Agricultural Resources Management Project.
24. Ismail, S., & Ata, S. (2005). An Analytical Study of Optimum Crop Pattern in Egypt. *Egyptian Journal of Agricultural Economics, 15(4),* 1175–1192.
25. Mohamad, N., & Said, F. (2011). A Mathematical Programming Approach to the Crop Mix Problem. *African Journal of Agricultural Research, 6*(1), 191–197.
26. El-Nahrawy, & Mohamed, A. (2011). Country Pasture/Forage Resource Profile: Egypt. FAO. Rome, Italy
27. Piech, B., & Rehman, T. (1993). Application of Multiple Criteria Decision Making Methods to Farm Planning: A Case Study. *Agricultural Systems, 41*, 305–319.
28. Sherbiny, N., & Zaki, M. (1976). Interregional Comparative Advantage Models in Developing Agriculture. *Journal of Development Studies, 4(2).* 3–17.
29. Siam, G. Crop "Production Planning in Egypt Using Linear Programming." (Unpublished doctoral dissertation), Cairo University, Cairo. 1973.
30. Siskos, Y., Despotis, D., & Ghediri, M. (1994). Multiobjective Modelling for Regional Agricultural Planning: Case Study in Tunisia. *European Journal of Operational Research, 77*, 375–391.

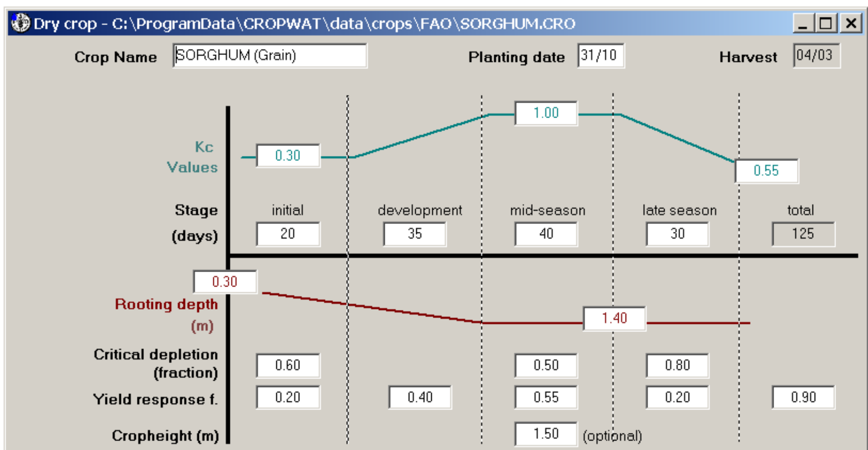
31. Schneider, u. (2009). Research Unit Sustainability and Global Change, Center for Marine and Atmospheric Sciences, KlimaCampus, Hamburg University, Germany,
32. Shatanawi, M. (2002). Policy Analysis of Water, Food Security and Agriculture Policies in Jordan, Review paper submitted to the World Bank.
33. Schönhart, M., Schmid, E., & Schneider, U. (2009). CropRota – A Model to Generate Optimal Crop Rotations from Observed Land Use. Working Paper 452009. Institute for Sustainable Economic Development, University of Natural Resources and Life Sciences, Vienna.
34. MAI, (2000). Agricultural Statistics Year Book.
35. MoEnv (Ministry of Environment, Jordan). Jordan's Second National Communication to the UNFCCC; Deposit No. 2009/11/4731; Ministry of Environment: Amman, Jordan, 2009
36. MWI (Ministry of Water and Irrigation, Jordan). Annual Report; MWI: Amman, Jordan, 2010.
37. MWI (Ministry of Water and Irrigation, Jordan). Special Report on Water Resources in Jordan; MWI: Amman, Jordan, 2009.
38. MWI (Ministry of Water and Irrigation, Jordan). Annual Report; MWI: Amman, Jordan, 2009.
39. NASS (National Agriculture Sector Strategy) 2012–2016, Ministry of Agriculture and Irrigation, Republic of Yemen
40. MAI, national conference on management and development of water resources in Yemen, held in January 2011
41. Ministry of Agriculture and Irrigation. (2000). National Action Plan to Combat Desertification. Republic of Yemen.
42. SADS. (2009). Sustainable Agricultural Development Strategy Towards 2030. Agricultural Research & Development Council. Arab Republic of Egypt, Ministry of Agriculture & Land Reclamation.
43. Scholte, P., Alkhulidi, A., & Kessler, J.J. (1991).The Vegetation of the Republic of Yemen [Western Part]. EPC and DHV Consulting. RLIP 1991.
44. Telahigue, T. (1998). Promotion of Traditional Grazing and Modern Pest Management Technique Component. FAO.

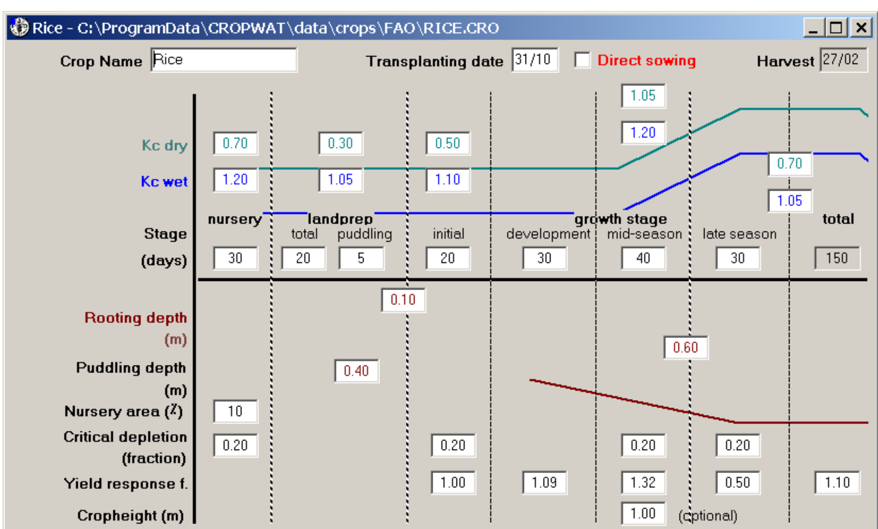
ANNEX I


Dry crop - C:\ProgramData\CROPWAT\data\crops\FAO\W-WHEAT.CRO
Crop Name
Winter Wheat f.f.
Planting date
31/10
Harvest
27/06
Kc
Values
0.70
1.15
0.25
Stage
(days)
initial
development
mid-season
late season
total
30
140
40
30
240
0.30
Rooting depth
(m)
1.50
Critical depletion
(fraction)
0.55
0.55
0.90
Yield response f.
0.20
0.60
0.50
0.40
1.00
Cropheight (m)
1.00
(optional)


Dry crop - C:\ProgramData\CROPWAT\data\crops\FAO\MAIZE.CRO
Crop Name
MAIZE (Grain)
Planting date
31/10
Harvest
04/03
Kc
Values
0.30
1.20
0.35
Stage
(days)
initial
development
mid-season
late season
total
20
35
40
30
125
0.30
Rooting depth
(m)
1.00
Critical depletion
(fraction)
0.55
0.55
0.80
Yield response f.
0.40
0.40
1.30
0.50
1.25
Cropheight (m)
2.00
(optional)


Dry crop - C:\ProgramData\CROPWAT\data\crops\FAO\BARLEY.CRO
Crop Name
Barley
Planting date
31/10
Harvest
27/02
Kc Values
0.30
1.15
0.25
Stage (days)
initial
development
mid-season
late season
total
15
25
50
30
120
0.30
Rooting depth (m)
1.10
Critical depletion (fraction)
0.55
0.55
0.90
Yield response f.
0.20
0.60
0.50
0.40
1.00
Cropheight (m)
1.00
(optional)


Dry crop - C:\ProgramData\CROPWAT\data\crops\FAO\SORGHUM.CRO
Crop Name
SORGHUM (Grain)
Planting date
31/10
Harvest
04/03
Kc Values
0.30
1.00
0.55
Stage (days)
initial
development
mid-season
late season
total
20
35
40
30
125
0.30
Rooting depth (m)
1.40
Critical depletion (fraction)
0.60
0.50
0.80
Yield response f.
0.20
0.40
0.55
0.20
0.90
Cropheight (m)
1.50
(optional)


Rice - C:\ProgramData\CROPWAT\data\crops\FAO\RICE.CRO
Crop Name
Rice
Transplanting date
31/10
Direct sowing
Harvest
27/02
Kc dry
0.70
0.30
0.50
1.05
0.70
Kc wet
1.20
1.05
1.10
1.20
1.05
nursery
landprep
growth stage
Stage (days)
total
puddling
initial
development
mid-season
late season
total
30
20
5
20
30
40
30
150
0.10
Rooting depth (m)
0.60
Puddling depth (m)
0.40
Nursery area (%)
10
Critical depletion (fraction)
0.20
0.20
0.20
0.20
Yield response f.
1.00
1.09
1.32
0.50
1.10
Cropheight (m)
1.00
(optional)

ANNEX II

CROP ROTATION AND CROP MIX

Crop rotation can be defined as "the decision to plant a sequence of crops in successive years on the same piece of land, while sustaining crop succession requirements" (Hildreth & Reither, 1951; Mohamad & Said, 2011). Heady (1948), tried to see the foremost profitable rotation of feed grains and forage crops by presenting a theoretical answer for the selection of output that maximizes farm profits exploitation the iso-revenue and iso-cost curves, through obtaining the very best iso-revenue in line with the iso-cost curve.

Further studies on crop rotations were tackled by many researchers using various mathematical techniques, such as linear programming (LP), non-linear programming (NLP), a multi-objective linear programming model (MOLP), and a linear optimization model (LOM).

LP was the foremost widely-applied technique to see the best land distribution in Egypt. Hanna (1970) used LP to see the best cropping pattern for Dakahlya governorate, whereas Siam (1973) applied LP to develop future crop production plans for every governorate. Maximizing net return for planned pattern was the objective function in both studies. Additionally, Sherbiny and Zaki (1976) used an LP model customized to the agronomic and institutional characteristics of Egyptian agriculture in order to assess the gains to be had from a more productive allotment of assets, which would be made possible by interregional specialization.

Non-linear programming (NLP) was utilized via specialists to figure out the ideal cropping pattern for Egypt. A study via Ismail and Ata (2005) modeled the ideal crop mix for Egypt utilizing a non-linear objective capacity that tried to amplify net benefit, subject to various direct imperatives ashore, water assets, work and capital. Information for the period 1990-2003 on 45 harvests were modeled. The outcomes of the study recommended that the proposed best cropping pattern for Egypt could generate a net return of EGP 410 million. In like manner, Aly et al. (2007) utilized an NLP model to determine the optimal cropping pattern in desert agriculture which relies on ground water by boosting the net income for every unit of irrigation ground water.

MOLP produces a set of proficient results, called “non-dominated” or “pareto-optimal solutions” (Piech and Rehman, 1993). Siskos et al. (1994) connected a multi-objective linear programming model to model the best land portion around diverse crops in Tunis. The target functions to be optimized enclosed increasing gross margin of profit, employment and forage production, additionally to minimizing seasonal labor and tractor utilization. El Sayed, L. M., Determining an optimum cropping pattern for Egypt, The American University in Cairo, 2012

CropRota: A Model to Generate Optimal Crop Rotations from Observed Land Use is among the LOM. CropRota generate optimal crop rotations for the particular scale by joining agronomic criteria and historical crop mixes at field, farm, or regional scales. Uwe (2009) applied and validated the model and empirical crop mix data for a case study region in Austria (Schönhart, 2009).